LOI #7

HOMESTAKE DUSEL
Deep Underground Science and Engineering Laboratory

*Yuri Kamyshkov*
*University of Tennessee*
*on behalf of*
*NNbar Collaboration*
*February 10, 2006*
*Lead, SD*

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*Letter of Interest*

# Search for Neutron-Antineutron Transition at Homestake DUSEL

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## $n \leftrightarrow \bar{n}$ ~~*baryon number*~~ $|\Delta B|=2$

← As was understood by A. Sakharov, 1967

- There are no laws of nature that would forbid the N ↔ Nbar transitions except the conservation of "*baryon charge (number)*":

*M. Gell-Mann and A. Pais, Phys. Rev. 97 (1955) 1387*
*L. Okun, Weak Interaction of Elementary Particles, Moscow, 1963*

- N ↔ Nbar was first suggested as a possible mechanism for explanation of Baryon Asymmetry of Universe *V. Kuzmin, 1970*

- N ↔ Nbar works within GUT + SUSY. First considered and developed within the framework of Unification models *R. Mohapatra and R. Marshak, 1979*

- Fast anomalous SM interactions (*sphalerons*) active in early Universe at TeV scales require that (B−L) should be violated *Kuzmin, Rubakov, Shaposhnikov, 1985*

- Several recent theory papers beyond SM related to N ↔ Nbar:

*K. Babu and R. Mohapatra, PLB 518 (2001) 269*
*S. Nussinov and R. Shrock, PRL 88 (2002) 171601*
*G. Dvali and G. Gabadadze, PLB 460 (1999) 47*
*H.Davoudiasl, et.al, PRL 93 (2004) 201301*
*B. Dutta, Y. Mimura, R. Mohapatra, 2005, arXiv:hep-ph/0510291*

arXiv:hep-ph/0510291

UMD-PP-05-052
MIFP-05-30

# Observable $N-\bar{N}$ Oscillation in High Scale Seesaw Models

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(Dated: October, 2005)

We discuss a realistic high scale ($v_{BL} \sim 10^{12}$ GeV) supersymmetric seesaw model based on the gauge group $SU(2)_L \times SU(2)_R \times SU(4)_c$ where neutron-anti-neutron oscillation can be in the observable range without fine tuning of parameters. This is contrary to the naive dimensional arguments which say that $\tau_{N-\bar{N}} \propto v_{BL}^5$ and should therefore be unobservable for seesaw scale $v_{BL} \geq 10^5$ GeV. Two reasons for this enhancement are: (i) accidental symmetries which keep some of the diquark Higgs masses at the weak scale and (ii) a new supersymmetric contribution from a lower dimensional operator. The net result is that $\tau_{N-\bar{N}} \propto v_{BL}^2 v_{wk}^3$ rather than $v_{BL}^5$. The model also can explain the origin of matter via the leptogenesis mechanism and predicts light diquark states which can be produced at LHC.

In the Supersymmetric Seesaw model describing the neutrino masses, leading N-Nbar operator was shown to have very weak power dependence on the seesaw scale i.e. $1/M^2_{seesaw}$ rather than $1/M^5_{seesaw}$ as in naive dimensional arguments. That makes N-Nbar observable within the reach of present experimental techniques. That also opens up the window for leptogenesis.

ELSEVIER

5 August 1999

Physics Letters B 460 (1999) 47–57

PHYSICS LETTERS B

# Non-conservation of global charges in the Brane Universe and baryogenesis

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Proton decay is strongly suppressed in this model, but n-nbar should occur since $n_R$ has no gauge charges

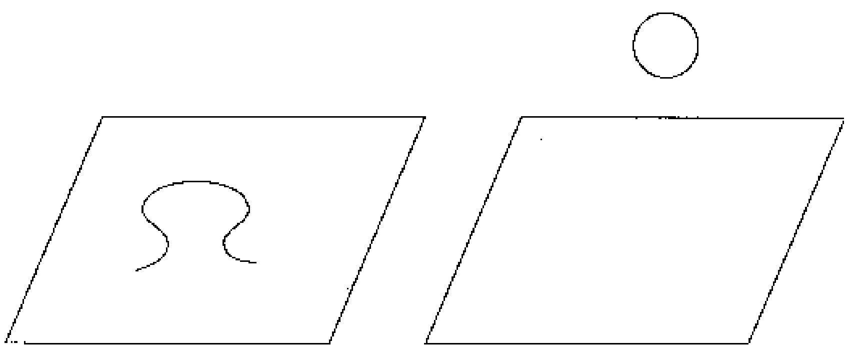


Fig. 1. Creation of baby branes.

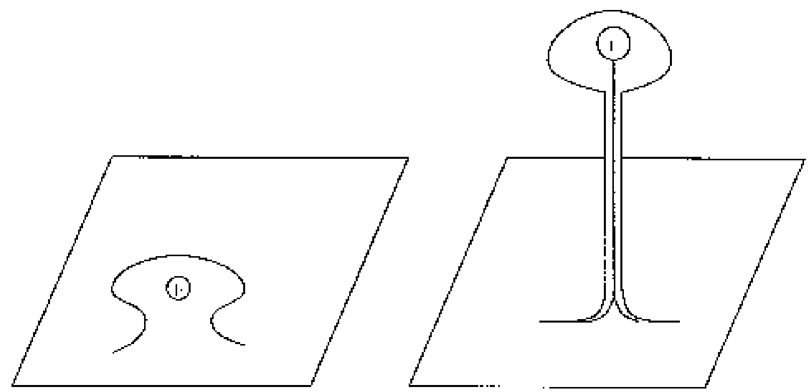


Fig. 2. Flux tube holding the baby brane with a local charge.

# Ideas of >2000 are different from 1980's:

$p\ ?\ \ e^{?}\pi^{0}, p\ ?\ \ ?K^{?}, etc.$

| 1980's | >2000 |
|---|---|
| GUT models conserving (B ?L) were though to work for BAU explanation [Pati & Salam'73, Georgi & Glashow'74…] | "Proton decay is not a prediction of baryogenesis!" [Yanagida'02] ? (B?L)?0 is needed fo r BAU [Kuzmin, Rubakov, Shaposhnikov'85…] |
| No indications for neutrino masses | m$_?$ ? 0 […S-K'98, SNO'02, KamLAND'03] and possible Majorana nature of neutrino |
| Great Desert [Giorgi & Glashow'74] from SUSY scale to GUT scale | No Desert. Possible unification wi th gravity at ~ 10 $^5$ GeV scale [Arkani-Hamed, Dimopoulos, Dvali'98 …] |
| **(B?L) = 0** in SM, SU(5), SUSY SO(10)… | **(B?L) ? 0** in ext. SUSY SO(10), L-R sym, QG $n\ ?\ \ \bar{n}, ?_R, 2?0?, n\ ?\ \ ???, etc.$ |
| Energy scale: 10 $^{15}$?10$^{16}$ GeV | Effective energy scale: above TeV |
| ? | ? |

**PDG 2004:**
Limits for both
free reactor neutrons and
neutrons bound inside nucleus

Bound n: J. Chung et al., (Soudan II)
Phys. Rev. D 66 (2002) 032004 $> 7.2 \cdot 10^{31}$ years $\Diamond$

Free n: M. Baldo-Ceolin et al., $\Rightarrow$
(ILL/Grenoble) *Z. Phys* **C63** (1994) 409
with $P = (t/\tau_{free})^2$

$$\tau_{bound} = R \cdot \tau_{free}^2$$

where $R \sim 10^{23}\, s^{-1}$

*R* is "nuclear suppression factor"
Uncertainty of *R* from nuclear
models is ~ factor of 2

## LIMIT ON $n\bar{n}$ OSCILLATIONS

### Mean Time for $n\bar{n}$ Transition in Vacuum

A test of $\Delta B$=2 baryon number nonconservation. MOHAPATRA 80 and MOHAPATRA 89 discuss the theoretical motivations for looking for $n\bar{n}$ oscillations. DOVER 83 and DOVER 85 give phenomenological analyses. The best limits come from looking for the decay of neutrons bound in nuclei. However, these analyses require model-dependent corrections for nuclear effects. See KABIR 83, DOVER 89, ALBERICO 91, and GAL 00 for discussions. Direct searches for $n \to \bar{n}$ transitions using reactor neutrons are cleaner but give somewhat poorer limits. We include limits for both free and bound neutrons in the Summary Table.

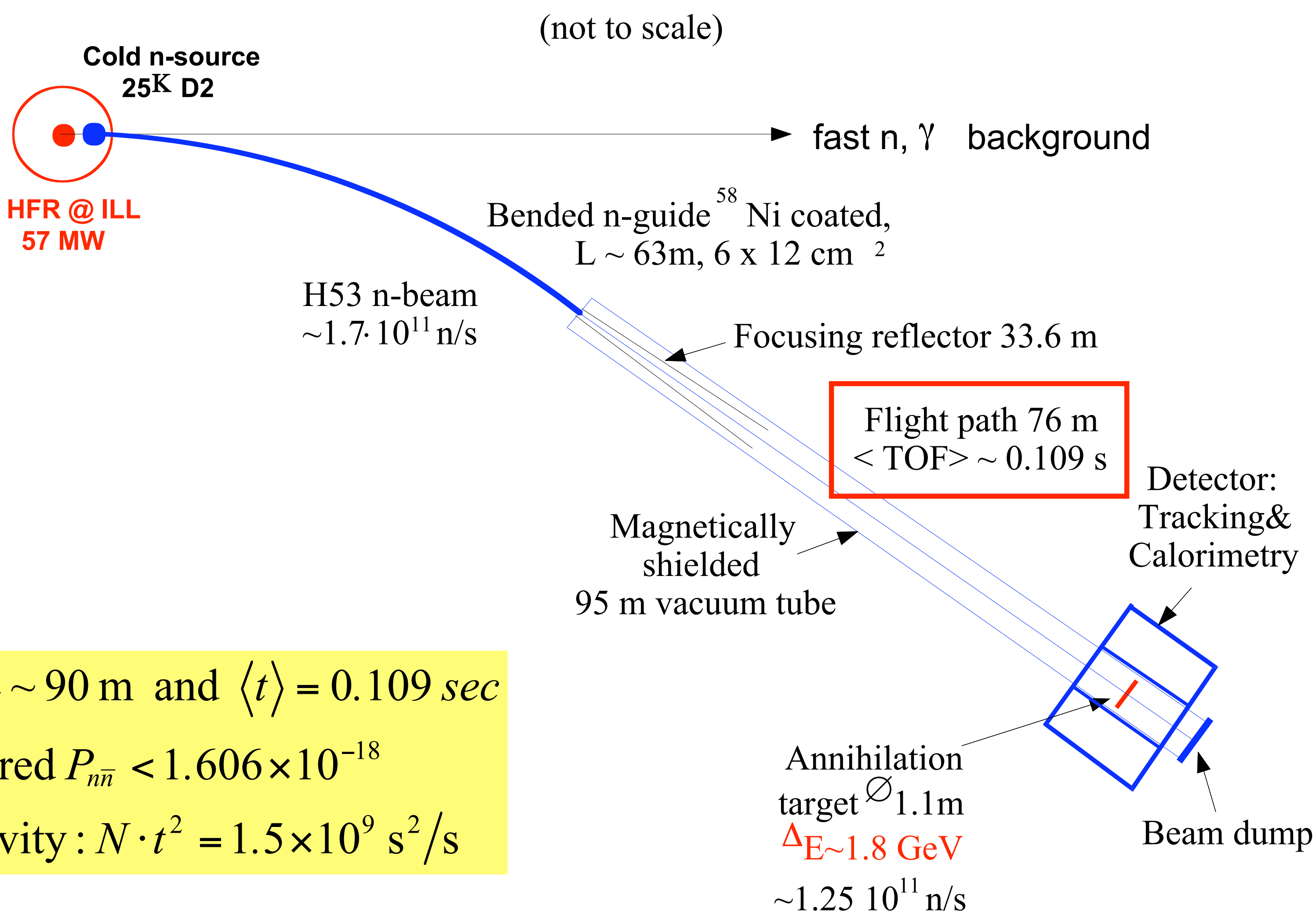
| VALUE (s) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **$>1.3 \times 10^8$** | 90 | CHUNG | 02B | SOU2 | $n$ bound in iron |
| **$>8.6 \times 10^7$** | 90 | BALDO-... | 94 | CNTR | Reactor (free) neutrons |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $>1 \times 10^7$ | 90 | BALDO-... | 90 | CNTR | See BALDO-CEOLIN 94 |
| $>1.2 \times 10^8$ | 90 | BERGER | 90 | FREJ | $n$ bound in iron |
| $>4.9 \times 10^5$ | 90 | BRESSI | 90 | CNTR | Reactor neutrons |
| $>4.7 \times 10^5$ | 90 | BRESSI | 89 | CNTR | See BRESSI 90 |
| $>1.2 \times 10^8$ | 90 | TAKITA | 86 | CNTR | $n$ bound in oxygen |
| $>1 \times 10^6$ | 90 | FIDECARO | 85 | CNTR | Reactor neutrons |
| $>8.8 \times 10^7$ | 90 | PARK | 85B | CNTR | |
| $>3 \times 10^7$ | | BATTISTONI | 84 | NUSX | |
| $> 2.7 \times 10^7 – 1.1 \times 10^8$ | | JONES | 84 | CNTR | |
| $>2 \times 10^7$ | | CHERRY | 83 | CNTR | |

Search with free neutrons is square
more efficient than with bound neutrons !

# Previous n-nbar search experiment with free neutrons

## At ILL/Grenoble reactor in 89-91 by Heidelberg-ILL-Padova-Pavia Collaboration

M.Baldo-Ceolin M. et al., Z. Phys., C63 (1994) 409




with $L \sim 90$ m and $\langle t \rangle = 0.109\ sec$

measured $P_{n\bar{n}} < 1.606 \times 10^{-18}$

sensitivity : $N \cdot t^2 = 1.5 \times 10^9\ s^2/s$

# Detector of Heidelberg -ILL-Padova-Pavia Experiment @ILL 1991

No background!
No candidates observed.
Measured limit for
a year of running:

$\tau_{n\bar{n}} \geq 8.6 \times 10^{7}\ sec$

= 1 unit of sensitivity

Volume 236, number 1 PHYSICS LETTERS B 8 February 1990

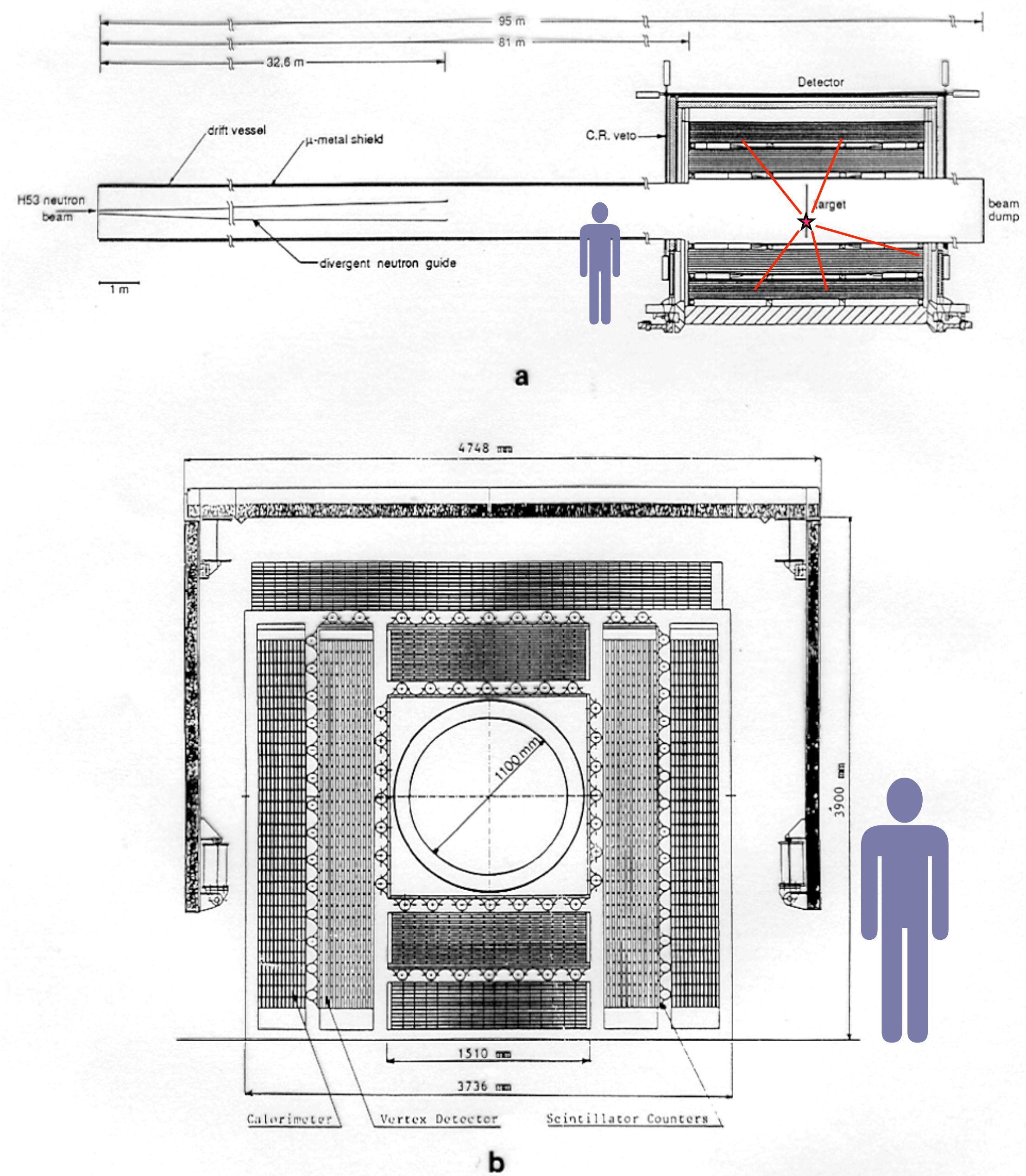



Fig. 1. (a) Experimental apparatus showing the "quasi free" neutron propagation length with the divergent guide, the target and the detection system. (b) Cross sectional view of the detector.

## How one can improve on such state-of-the-art experiment and achieve 3-4 orders of magnitude higher sensitivity?

Two major improvements:

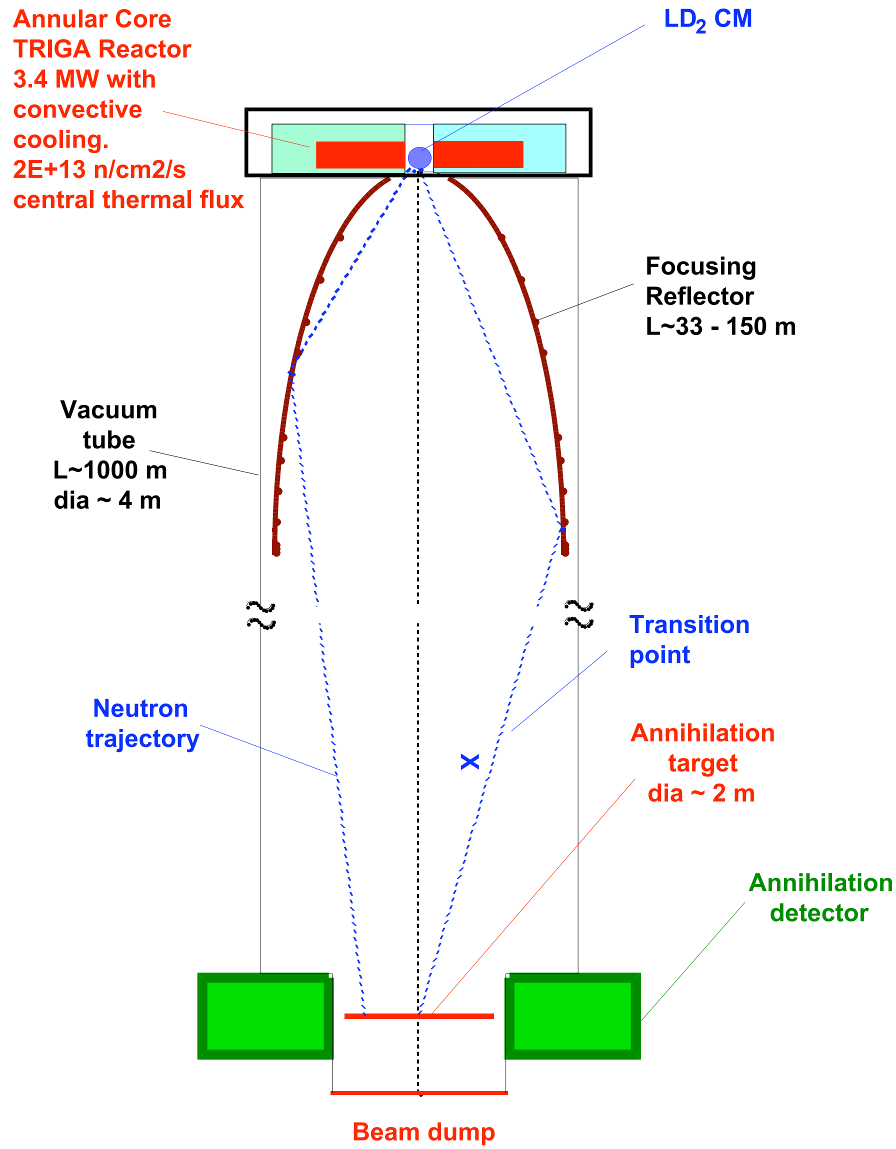
1. Focusing of neutrons: use of larger solid angle
2. Vertical layout: compensating Earth gravity

   (even with weaker neutron source)

# N-Nbar search experiment with vertical layout at Homestake

- Dedicated small-power research reactor with cold neutron moderator → $V_n \in 1000$ m/s
- Vertical shaft /1000 m deep with diameter ∕5 m
- Large vacuum tube, focusing reflector; Earth magnetic field compensation system ~ nT
- Detector (similar to ILL N-Nbar detector) at the bottom of the shaft (no new technologies)
- No background: one event→ discovery!

The possibility of a large increase in sensitivity of the experimental search for n →anti-n transition is a central motivation of our LOI



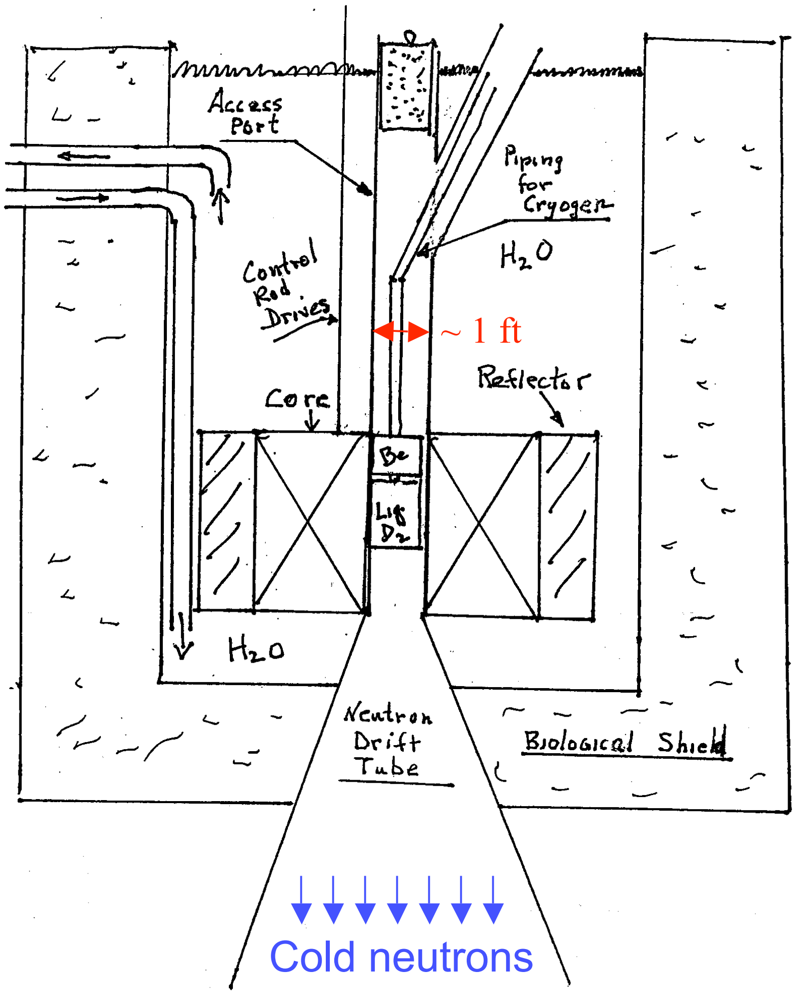

*Not to scale*

Neutron source needed:
small power 3.4 MW
TRIGA reactor

**TRIGA Reactor**
**Courtesy of General Atomics**

Fig. 17. Dry central cavity in annular core

# Annular core TRIGA reactor (GA) for N-Nbar search experiment




Courtesy of W. Whittemore
(General Atomics)

- GA built ~ 70 TRIGA reactors 0.01÷14 MW (th)
- 19 TRIGA reactors are presently operating in US (last commissioned in 1992)
- 25 TRIGA reactors operating abroad (last commissioned in 2005)
- some have annular core and vertical channel
- most steady, some can be pulsed up to 22 GW
- safe ~ 20% EU uranium-zirconium hydride fuel

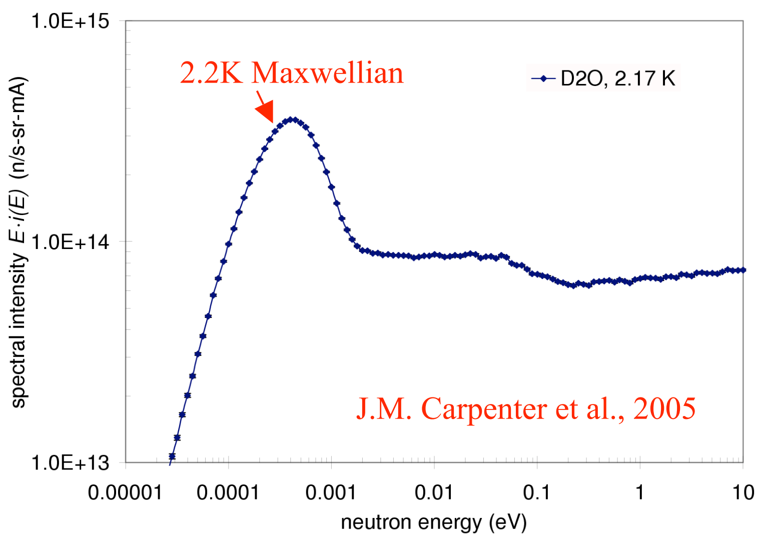
Economic solution for n-nbar:
annular core TRIGA reactor 3.4 MW
with convective cooling, vertical channel,
and large cold $LD_2$ moderator ($T_n$ ~ 35K).
Unperturbed thermal flux in the vertical
channel ~ $2\times10^{13}$ n/cm$^2$/s

# New development enhancing n-nbar search sensitivity

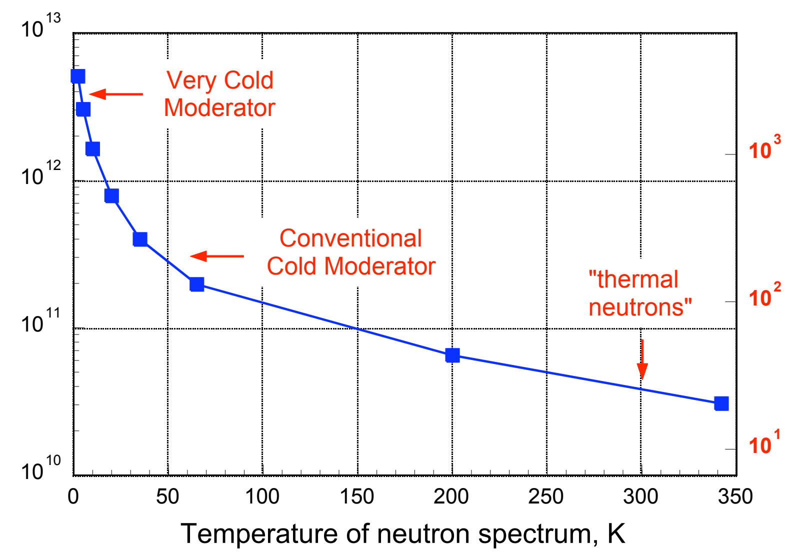
Very Cold Neutron Source with $T_n \sim 2.2K$

(IPNS/ANL R&D project by J.M. Carpenter et al., 2005)

Neutron Intensity from $D_2O$ Ice Moderator
Model A




MC simulation: source dia 25 cm, target dia 2m, L(S-T) = 1150 m
$3\theta_c$ reflector starts at z=2m with dia 1 m; ends at z=33 m with dia 4 m



# $n \rightarrow \bar{n}$ Search Sensitivity

Soudan-II limit ≈ ILL/Grenoble limit = 1 unit of sensitivity

| *Method* | *Present limit* | *Possible future limit* | *Possible sensitivity increase factor* |
|---|---|---|---|
| Intranuclear (N-decay expts) | $7.2 ?10^{31}$ yr = 1 *unit* Soudan II | $7.5 ?10^{32}$ yr (Super-K) $4.8 ?10^{32}$ yr (SNO) | ? 11 |
| Geo-chemical (ORNL) | none | $4 ?10^{8} ? 1 ?10^{9}$ s (Tc in Sn ore) | ? 20 ? 100 |
| UCN trap (6? $10^{7}$ ucn/sec) | none | ~ $1 ?10^{9}$ s | ? 100 |
| Cold horizontal beam | $8.6 ?10^{7}$ s = 1 *unit* @ILL/Grenoble | $3 ?10^{9}$ s @HFIR/ORNL **Not available** | ? $10^{3}$ |
| Cold Vertical beam | none | $3 ?10^{9} – 1 ?10^{10}$ s (Homestake DU SEL) | ? $10^{3} ? 10^{4}$ |

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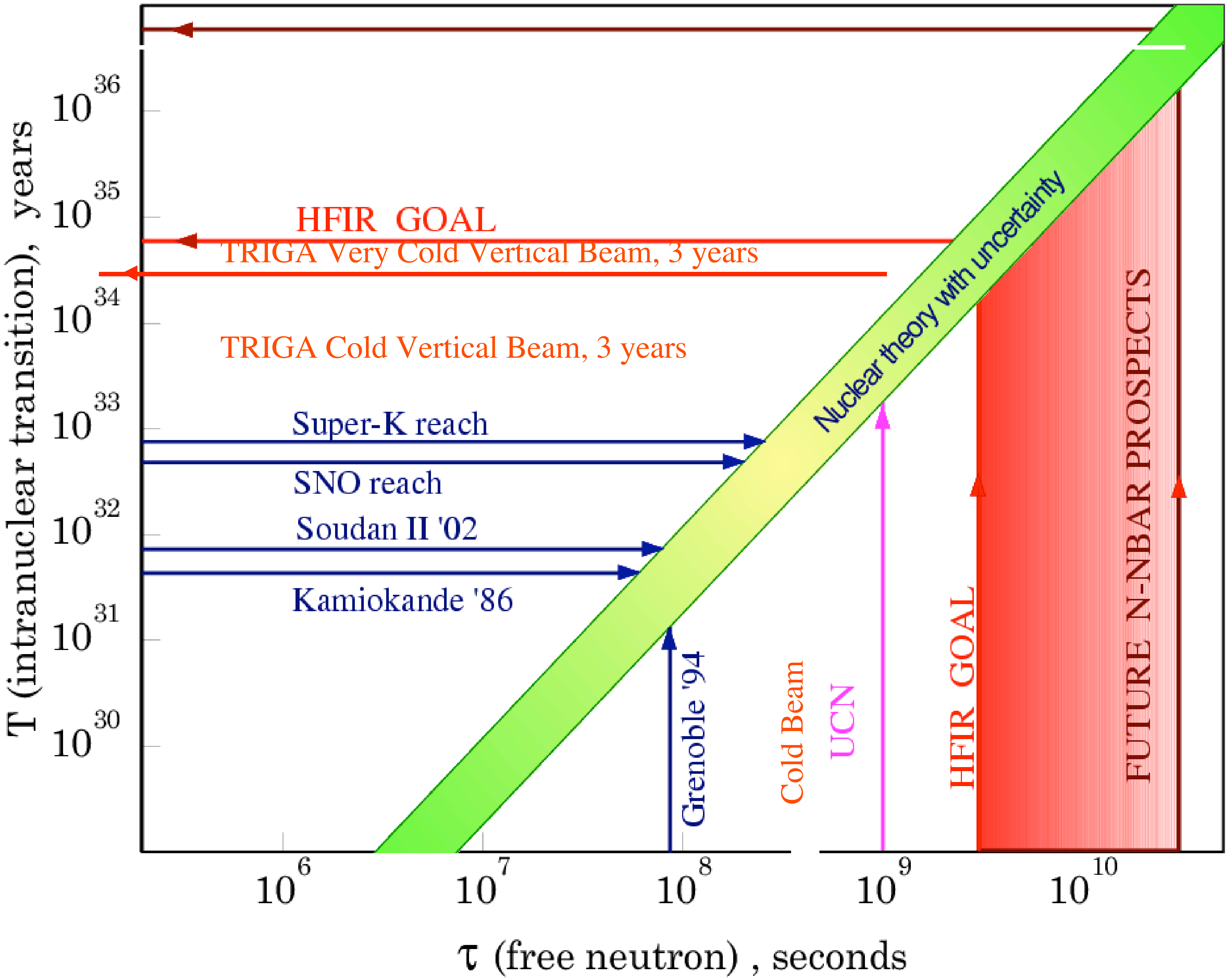
HFIR GOAL
TRIGA Very Cold Vertical Beam, 3 years
TRIGA Cold Vertical Beam, 3 years
Super-K reach
SNO reach
Soudan II '02
Kamiokande '86
Nuclear theory with uncertainty
Grenoble '94
Cold Beam
UCN
HFIR GOAL
FUTURE N-NBAR PROSPECTS
T (intranuclear transition), years
$10^{30}$
$10^{31}$
$10^{32}$
$10^{33}$
$10^{34}$
$10^{35}$
$10^{36}$
$10^{6}$
$10^{7}$
$10^{8}$
$10^{9}$
$10^{10}$
τ (free neutron) , seconds

# Possible impact of NNbar search at Homestake

***If discovered:***

- $n \rightarrow \bar{n}$ will establish a new force of nature and a new phenomenon leading to the physics at the energy scale of $> 10^5$ GeV
- will provide an essential contribution to the understanding of BAU
- might be the first detected manifestation of extra dimensions and low QG scale
- new symmetry principles can be experimentally established: $\Delta(B-L)\neq 0$
- further experiments with free neutrons will allow high-sensitivity testing
  - whether $m_n = m_{\bar{n}}$ (CPT theorem) with $\Delta m/m \approx 10^{-23}$ *(L. Okun et al, 1984)*
  - gravitational equivalence of baryonic matter and antimatter *(S. Lamoreaux et al, 1991)*

***If NOT discovered:***

- within the reach of improved experimental sensitivity will set a new limit on the stability of matter exceeding sensitivity of X-large nucleon decay experiments
- wide class of SUSY-based models will be removed *(K. Babu and R. Mohapatra, 2001)*

# Timeline of NNbar project development at Homestake

- NNbar in not being proposed for the initial suit of experiments: not conventional approach, no tradition of such experiments in US, need time to grow dedication of the community; need to implement the scheme of ownership of the reactor. Important to start the process and related studies asap.
- Stage 0: **PAC endorsement of NNbar physics**
- Stage 1(~ 1-2 yr): R&D studies with Homestake, cost understanding
- Stage 2 (~1-2 yr): Proposal→approval with funding agencies. CD0
- Stage 3 (~1yr): TDR, reviews, approvals
- Stage 4 (~2 yr): construction
- ~ 3 years of running

# What is required for NNbar experiment at Homestake?

- Vertical shaft ~ 1 km deep, with dia ≥ 5 m to be instrumented
- Construction access from the top and the bottom of the shaft
- Site isolated from the main underground lab
- Are reactor *n* are background problem for other expts?
- Reactor ν might be a problem for geo-neutrino studies...
- Heat removal of 3.5 MW TRIGA reactor (at the surface)
- Cryogen equipment for cold moderator (at the surface)
- Many other things (may be too early to discuss)